APPARATUS FOR MEASURING A PROPERTY OF
A CIGARETTE PAPER WRAPPER AND ASSOCIATED METHOD

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to smoking articles and, more particularly, to an apparatus for measuring a property of a paper material suitable for use as components of such smoking articles.

Description of Related Art

Popular smoking articles, such as cigarettes, have a substantially cylindrical rod shaped structure and include a charge, roll or column of smokable material such as shredded tobacco (e.g., in cut filler form) surrounded by a paper wrapper thereby forming a so-called "tobacco rod." Normally, a cigarette has a cylindrical filter element aligned in an end-to-end relationship with the tobacco rod. Typically, a filter element comprises plasticized cellulose acetate tow circumscribed by a paper material known as "plug wrap." Certain cigarettes incorporate a filter element having multiple segments, and one of those segments can comprise activated charcoal particles. Typically, the filter element is attached to one end of the tobacco rod using a circumscribing wrapping material known as "tipping paper." It also has become desirable to perforate the tipping material and plug wrap, in order to provide dilution of drawn mainstream smoke with ambient air. A cigarette is employed by a smoker by lighting one end thereof and burning the tobacco rod. The smoker then receives mainstream smoke into his/her mouth by drawing on the opposite end (e.g., the filter end) of the cigarette.

Numerous references propose various types of cigarettes possessing various types of paper wrapping materials. See, for example, U.S. Patent Nos. 1,909,924 to

Schweitzer; 4,489,650 to Weinert; 3,030,963 to Cohn; 4,146,040 to Cohn; 4,489,738 to Simon; 4,615,345 to Durocher; 4,607,647 to Dashley; 5,060,675 to Milford *et al.*; 4,924,888 to Perfetti *et al.*; 5,143,098 to Rogers *et al.*; 4,998,543 to Goodman; 5,220,930 to Gentry; and 5,271,419 to Arzonico *et al.* Some paper wrapping materials are so-called "banded papers" and possess segments defined by the composition, location and properties of the various materials within those wrapping materials. Numerous references contain disclosures suggesting various banded wrapping material configurations. See, for example, U.S. Patent Nos. 1,996,002 to Seaman; 2,013,508 to Seaman; 4,452,259 to Norman *et al.*; 5,417,228 to Baldwin *et al.*; 5,878,753 to Peterson *et al.*, 5,878,754 to Peterson *et al.*; and 6,198,537 to Bokelman *et al.*; and PCT WO 02/37991. Methods for manufacturing banded-type wrapping materials also have been proposed. See, for example, U.S. Patent Nos. 4,739,775 to Hampl, Jr.; 5,474,095 to Allen *et al.*; and PCT WO 02/44700 and PCT WO 02/055294. Some references further describe banded papers having segments of paper, fibrous cellulosic material or particulate material adhered to a paper web. See, for example, U.S. Patent Nos. 5,191,906 to Myracle, Jr.; 5,263,999 to Baldwin *et al.*; 5,417,228 to Baldwin *et al.*; and 5,450,863 to Collins *et al.*; and U.S. Patent Application Publication No. 2002/0092621 to Suzuki. In addition, some references describe apparatuses and method for inspecting such papers and wrapping materials, some of which may be capable of operating in an automated and/or high speed process. See, for example, U.S. Patent Nos. 4,845,374 to White *et al.*; 5,966,218 to Bokelman *et al.*; 6,020,969 to Struckhoff *et al.*; and 6,198,537 to Bokelman *et al.*; U.S. Patent Application Publication Nos. 2003/0145869 and 2003/0150466 to Kitao *et al.*, and 2003/0197126 to Sato *et al.*; and U.S. Patent Application Serial Nos. 10/645,996, filed August 22, 2003, and 10/665,066, filed September 17, 2003.

Since certain properties are often required to provide the desired burn characteristics and/or other characteristics of such wrapping materials and since consistency between individual paper wrappers for a particular product is also desired, it has been desirable, if not necessary, to determine certain physical properties or characteristics of wrapping materials for smoking articles. For example, techniques for measuring the air permeability or porosity of such wrapping papers, as well as the

diffusion of gases, such as carbon monoxide, through such wrapping papers, have been developed. For example, the CORESTA method (CORESTA Publication ISO/TC0126/SC I N159E (1986)) details a procedure for measuring air flow through paper with a specified pressure difference across the paper. This procedure may generally provide accurate readings for large sample areas or relatively high flow rates. However, this method may also be undesirably subject to high relative errors and high variability for small sample areas and low flow rates.

Further, for example, Drake *et al.* (D.G. Drake, D.S. Riley, R.R. Baker and K.D. Kilburn, *On a Cell to Measure Diffusion Coefficients of Gases Through Cigarette Papers*, Int. J. Heat and Mass Transfer, 23 (1980) 127-134) describe a procedure for direct measurement of paper diffusion coefficients. However, this reference does not describe an apparatus suitable for measuring small band areas of a sample. In addition, Durocher (U.S. Patent No. 4,615,345 and other patents) describes an indirect and destructive sample test producing results asserted to be proportional to paper diffusion coefficients. However, such a method is undesirably limited by destruction of the sample and the amount of time required to perform the test.

Thus, there exists a need for an apparatus and method capable of nondestructively measure certain physical properties or characteristics of wrapping papers, such as those used for the manufacture of smoking articles. Such an apparatus and method should be capable of expeditiously determining the value of the particular characteristic for the tested sample of the wrapping paper and, in some instances, would desirably have the capability of being applied in an automated and/or high speed process to perform regular or random evaluations of the paper wrappers. Further, such an apparatus and method should desirably be nondestructive to the paper wrapper, applicable to a small area of the paper wrapper (sample), cost and time effective, and capable of being implemented in an environmentally friendly manner.

BRIEF SUMMARY OF THE INVENTION

The above and other needs are met by the present invention which, in one embodiment, provides an apparatus adapted to measure a property of a cigarette paper wrapper. Such an apparatus includes a sampling device defining a first chamber portion

and a corresponding second chamber portion, wherein the first and second chamber portions engage at and define a sampling area. The sampling device is configured to receive the cigarette paper wrapper such that the cigarette paper wrapper spans the sampling area and separates the first chamber portion from the second chamber portion. A first gas source is configured to supply a regulated flow of a carrier gas to the first chamber portion, while a second gas source is configured to supply a regulated flow of a detectable gas to the second chamber portion. An analyzer device in communication with the first chamber portion is configured to receive a resultant gas flow, wherein the resultant gas flow includes the carrier gas and any of the detectable gas entering the first chamber portion through the cigarette paper wrapper. The analyzer device is further configured to be capable of determining an amount of the detectable gas in the resultant gas flow so as to thereby determine a property of the cigarette paper wrapper, such as the diffusion coefficient with respect to the detectable gas.

Another advantageous aspect of the present invention comprises a method of measuring a property of a cigarette paper wrapper. First, a cigarette paper wrapper is received in a sampling device defining a first chamber portion and a corresponding second chamber portion, wherein the first and second chamber portions engage at and define a sampling area. The sampling device is further configured to receive the cigarette paper wrapper such that the cigarette paper wrapper spans the sampling area and separates the first chamber portion from the second chamber portion. A regulated flow of a carrier gas is then supplied to the first chamber portion, while a regulated flow of a detectable gas is supplied to the second chamber portion. A resultant gas flow is thereafter received at an analyzer device in communication with the first chamber portion, wherein the resultant gas flow including the carrier gas and any of the detectable gas entering the first chamber portion through the cigarette paper wrapper. An amount of the detectable gas in the resultant gas flow is then determined with the analyzer device, from which a property of the cigarette paper wrapper, such as the diffusion coefficient with respect to the detectable gas, is determined.

Thus, embodiments of the present invention meet the above-identified needs and provide distinct advantages as further detailed herein.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a schematic of an apparatus adapted to measure a property of a cigarette paper wrapper according to one embodiment of the present invention.

FIG. 2 is a schematic plan view of a banded cigarette paper wrapper advancing through an apparatus adapted to measure a property of a cigarette paper wrapper according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present inventions now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, these inventions may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

FIG. 1 schematically illustrates an apparatus, indicated generally by the numeral **10**, adapted to measure a property of a cigarette paper wrapper according to one embodiment of the present invention, wherein the apparatus **10** may be used, for example, to evaluate various types of paper wrapping materials and treated wrapping materials as disclosed in U.S. Patent Application Publication No. 2003/0131860 to Ashcraft *et al.*, which is incorporated herein in its entirety by reference. Such an apparatus **10** comprises a sampling device **100** defining a first chamber portion **150** and a corresponding second chamber portion **200**. The first and second chamber portions **150, 200** are configured to be capable of engaging about a sampling area **250**, wherein the sampling area **250** is defined by one or more dimensions. The sampling device **100** is further configured to receive a cigarette paper wrapper **50** between the first and second chamber portions **150, 200**. Preferably, the sampling area **250** and/or the cigarette paper wrapper **50** are dimensioned such that the cigarette paper wrapper **50** spans the sampling area **250** and extends sufficiently beyond the sampling area **250** so as to be capable of being secured between the first and second chamber portions **150, 200**. For example, the

first and second chamber portions **150, 200** may be movable with respect to each other so as to allow the cigarette paper wrapper **50** to be placed therebetween. Such a cigarette paper wrapper **50** may vary considerably in, for example, composition and characteristics, some of which are described in, for instance, U.S. Patent Application Publication No. 2003/0131860, also assigned to the assignee of the present invention. Accordingly, U.S. Patent Application Publication No. 2003/0131860 is incorporated herein in its entirety by reference.

In a particularly advantageous embodiment, the engaging faces of the first and second chamber portions **150, 200** are configured to be brought together, with the cigarette paper wrapper **50** therebetween, so as to form a seal therewith. For example, the engaging faces of the first and second chamber portions **150, 200** may be machined to respective flat surfaces or into any other suitable complementary configuration. However, if necessary, each of the first and second chamber portions **150, 200** may have, for instance, a gasket **140** on the engaging faces thereof surrounding the sampling area **250**. Such a configuration is shown in **FIG. 1**, but it will be understood that the gaskets **140** may not be necessary in light of the particularly advantageous gasket-less embodiment previously described. If gaskets **140** are used, the gaskets **140** form a seal between the respective chamber portion and the cigarette paper wrapper **50** when the cigarette paper wrapper **50** is placed between the first and second chamber portions **150, 200** and the first and second chamber portions **150, 200** are brought together. In particularly advantageous instances, with or without the gaskets **140**, the first and second chamber portions **150, 200** are configured to form a substantially air-tight seal about the cigarette paper wrapper **50**. One skilled in the art will appreciate, however, that many different configurations for sealing the cigarette paper wrapper **50** between the first and second chamber portions **150, 200** may be possible, preferably without causing damage or deformity to the cigarette paper wrapper **50**, and that the configurations presented herein are merely examples thereof. In any instance, the cigarette paper wrapper **50** essentially separates the first chamber portion **150** from the second chamber portion **200** when secured therebetween.

Each of the first and second chamber portions **150, 200** further includes a respective gas inlet port **160, 210** and a respective gas outlet port **170, 220**. The gas inlet

port **160** of the first chamber portion **150** is connected a gas supply **180** of a carrier gas. According to one advantageous embodiment of the present invention, the carrier gas is substantially inert, comprising, for example, nitrogen, helium, argon, or the like. Further, the gas inlet port **210** of the second chamber portion **200** is connected to a gas supply **230** of a detectable gas. In one advantageous embodiment, the detectable gas is detectable over the carrier gas. In addition, the detectable gas is preferably substantially harmless if released to atmosphere. As such, the detectable gas may comprise, for example, carbon dioxide, oxygen, or the like. Respective gas flow regulating devices such as, for example, mass flow meters **190, 240**, are disposed between the gas supplies **180, 230** and the respective gas inlet ports **160, 210** for regulating the flows of the gases. In advantageous instances, the mass flow meters **190, 240** are adjustable such that substantially equal mass flows of the respective gases are directed to flow into the first and second chamber portions **150, 200** through the gas inlet ports **160, 210** such that the pressures in the chamber portions **150, 200** are also substantially equal. In this manner, the gases do not provide a driving force in either direction through the cigarette paper wrapper **50**. In one advantageous embodiment, the apparatus **10** is operated such that the pressures in the chamber portions **150, 200** are close to atmospheric pressure.

The detectable gas leaving the second chamber portion **200** through the gas outlet port **220** may, in some instances, be vented directly to atmosphere. However, in other instances, where the detectable gas cannot be safely vented to atmosphere, one skilled in the art will appreciate that the waste detectable gas may be directed to a variety of devices for collecting, neutralizing, and/or otherwise converting the detectable gas into a form suitable for disposal. The gas outlet port **170** of the first chamber portion **150**, however, is connected to an analyzer device **300**. Such a connection can be established, for example, through the use of a sample loop (not shown) or other mechanism configured so as to avoid elevating the pressure in the first chamber portion **150** over the second chamber portion **200**. The analyzer device **300** is thus configured to receive a resultant gas flow from the first chamber portion **150**, wherein the resultant gas flow is comprised of the carrier gas and any of the detectable gas that diffuses across the cigarette paper wrapper **50** from the second chamber portion **200** into the first chamber portion **150**. As such, in one advantageous embodiment, the analyzer device **300** is

configured to be capable of conducting at least one analysis to determine the amount of the detectable gas in the resultant gas flow. Such an analysis can indicate, for instance, the diffusivity or diffusion coefficient of the cigarette paper wrapper **50** as described herein in further detail. In some instances, under the conditions in the sampling device **100**, the diffusion of the detectable gas across the cigarette paper wrapper **50** may require a certain amount of time to reach an equilibrium, after which time the amount of the detectable gas in the resultant gas flow remains substantially constant. Accordingly, the analyzer device **300** may be configured, for example, to make several measurements or analyses in order to determine when such an equilibrium has been reached, or to perform the measurement following a certain elapsed time from the start of the test for the particular cigarette paper wrapper **50**. For instance, the analyzer device **300** may be configured to perform the necessary measurement at between about 3 seconds and about 10 seconds after the test process is initiated.

According to one advantageous aspect of the present invention, the diffusivity of the cigarette paper wrapper **50** can be determined according to the following methodology. More particularly, a sample of a cigarette paper wrapper **50** is first placed between the first and second chamber portions **150, 200** so as to span the sampling area **250**. Once the wrapper **50** is secured between the chamber portions **150, 200**, a steady stream of a substantially inert carrier gas, such as N_2, is fed into the first chamber portion **150** through the gas inlet port **160** thereof, while a steady stream of a detectable gas, such as CO_2, is fed into the second chamber portion **200** through the gas inlet port **210** thereof. Since cigarette paper wrapper **50** is at least partially porous, some CO_2 detectable gas will tend to migrate from the second chamber portion **200**, through the wrapper **50**, and into the N_2 carrier gas stream (and likewise, some of the N_2 carrier gas will tend to migrate through the wrapper **50** and into the CO_2 detectable gas stream). The rate at which the detectable gas migration occurs is related to, for example, the diffusion coefficient of the wrapper (D_P), the binary diffusion coefficient of CO_2 into N_2 ($D_g = .171\ cm^2/s$), the temperature (T), the differential pressure (ΔP), and the gas concentration differential between the first and second chamber portions **150, 200**. The diffusion coefficient D_p of the wrapper **50** can be subsequently calculated, for instance, from the concentration of the

detectable gas in the resultant gas flow (the measured outlet gas concentration (C_{out})) and the aforementioned parameters.

One skilled in the art will also appreciate that the concentration of the respective gas in each chamber portion **150, 200** may change along the length of the sampling area **250** ($\delta C/\delta x$) depending on the amount of the respective gas migrating across the wrapper **50**. Likewise the concentration of the respective gas will vary over the depth of the respective chamber portions **150, 200** ($\delta C/\delta z$), corresponding to a distance away from the sample of the wrapper **50**. Thus, taking these various factors into consideration, the resultant system of partial differential equations relating the concentration of the detectable gas in the resultant gas flow (%CO_2) in the first chamber portion **150** to the diffusion coefficient D_p of the cigarette paper wrapper **50** (as discussed in D.G. Drake, D.S. Riley, R.R. Baker and K.D. Kilburn, *On a Cell to Measure Diffusion Coefficients of Gases Through Cigarette Papers*, Int. J. Heat and Mass Transfer, 23 (1980) 127-134, the contents of which are incorporated herein by reference) may have the general form:

$$\theta_m = 2\alpha^2 \sum_{n=1}^{\infty} \frac{1}{\mu_n^2\left[\mu_n^2 + \alpha^2 + \alpha\right]} e^{-6\mu_n^2 \chi} \qquad \text{Eqn. 1}$$

where μ_n are the positive roots of

$$\mu \tan \mu = \alpha \qquad \text{Eqn. 2}$$

Further:

$$\theta_m = 2C_{out} / C_{CO2} - 1 \qquad \text{Eqn. 3}$$

$$\chi = bD_g x / 6Ve \qquad \text{Eqn. 4}$$

$$\alpha = 2eD_p / tD_g \qquad \text{Eqn. 5}$$

where: C_{CO2} = input CO_2 concentration = 100%;

b = chamber portion width;

x = chamber portion length;

V = volumetric flow rate;

e = chamber portion depth; and

t = wrapper thickness.

The solution is subsequently determined, for example, by a numerical iteration procedure, as follows:

1) Determine an initial estimate for D_p;
2) Calculate α using Eqn. 5;
3) Determine the first ten positive values for μ that satisfy Eqn. 2;
4) Calculate C_{out} as predicted by Eqn. 1;
5) Compare to calculated C_{out} to C_{out} actually measured; and
6) Increment D_p and repeat steps 2-5 until calculated C_{out} is within 0.01% of C_{out} actually measured.

D_p, expressed in units of, for example, cm^2/s, describes a rate of migration through a material and is independent of the material's geometry. Further, a cigarette burn rate is at least partly governed by the amount of oxygen that diffuses from ambient through the cigarette paper wrapper **50** and into the fire coal. Accordingly, another relevant measurement may be a diffusive flux (D*) across the cigarette paper wrapper **50**, expressed in terms of volume of gas per unit area per unit time ($cm^3/cm^2/s$ or cm/s). D* may also be expressed as the ratio of D_p and the wrapper thickness t ($D^* = D_p/t$).

In order to simplify these calculations for routine use, D* and C_{out} as calculated can be related with the aforementioned procedure at standard ambient conditions (725 torr, 299°K) by, for example, a fourth degree polynomial regression (at least partially dependent on the dimensions of the chamber) having an applicable equation as follows:

$$D^*_s = \lambda_4 C_{out}{}^4 + \lambda_3 C_{out}{}^3 + \lambda_2 C_{out}{}^2 + \lambda_1 C_{out} \qquad \text{Eqn. 6}$$

wherein this equation is applicable to a chamber having particular dimensions for chamber width (b = 0.4 cm), chamber length (x = 2.0 cm), and chamber depth (d = 0.175 cm), and

where: λ_4 = 1.530E-04;

λ_3 = -7.513E-04;

λ_2 = 8.624E-03; and

λ_1 = 1.184E-01.

D^*_s thus denotes the diffusion coefficient at the standard environmental conditions and for the specific chamber dimensions described above. However, in instances where a controlled mass flow is fed into the respective chamber portions **150, 200**, the volumetric flow and resultant D* must be corrected for temperature and barometric pressure, as follows:

$$D^* = D^*_s \times \frac{725}{P_a} \times \frac{T_a}{299} \qquad \text{Eqn. 7}$$

where: P_a = ambient pressure; and

T_a = ambient temperature.

The flow rates of both the carrier gas and the detectable gas may be readily determined from the respective mass flow meters **190, 240**. As such, the diffusion coefficient D_p of the cigarette paper wrapper **50** may be determined using the described apparatus **10**, as detailed, according to embodiments of the present invention.

In some instances, as shown in **FIG. 2**, the cigarette paper wrapper **50** may be provided as a contiguous roll **350** of cigarette paper wrappers **50**, wherein, in some instances, each cigarette paper wrapper **50** may comprise two contiguous bands **60, 70** though, in some instances, each cigarette paper wrapper **50** may comprise more than two bands. According to other aspects of the present invention, the bands **60, 70** can have different values of a common property, as will be appreciated by one skilled in the art.

For example, one band may have a greater diffusion coefficient than the other band. When arranged along the roll **350**, the bands **60, 70** are regularly repeating. As such, in some instances, the apparatus **10** may be configured to selectively perform a measurement of either or both bands **60, 70** at selected points along the roll **350**. In such instances, the apparatus **10** further includes an advancement device **400** for advancing the cigarette paper wrappers **50** from the roll **350** through the sampling device **100**.

One skilled in the art will further appreciate that embodiments of the apparatus **10**, applicable to a roll **350** of cigarette paper wrappers **50**, may be configured in many different manners. For example, the apparatus **10** may be configured to perform a measurement of each and every band **60, 70** along the roll **350**. However, such a configuration may not be practical in a manufacturing process. Accordingly, the apparatus **10** may be configured so as to selectively perform a measurement at various intervals along the roll **350**. For example, the apparatus **10** may be configured to measure each tenth occurrence of the first band **60** and/or the second band **70**. In such instances, the apparatus **10** may further include a sensor **450** operably engaged with the advancement device **400** and capable of directing the advancement device **400** to stop the advancement of the cigarette paper wrappers **50** on the roll **350** when a certain point on the roll **350** is reached such that a particular band lies within the sampling device **100**. More particularly, the sensor **450** may be configured to analyze the roll **350** so as to direct the advancement device **400** to stop the advancement of the cigarette paper wrappers **50** when only one of the bands **60, 70** is spanning the sampling area **250** within the gaskets **140**. Such a sensor **450** may comprise an optical sensor, though one skilled in the art will appreciate that many different types of sensors and/or other mechanisms may be implemented to accomplish the selective stopping of the advancement of the roll **350** as described herein. For example, a registration and inspection system (not shown) may be implemented, wherein such a system may include, for instance, a detection apparatus utilizing a spectroscopic (non-optical) system such as a non-contact ultrasonic transmission system or a near infrared (NIR) absorption system.

In addition, in other instances, the apparatus **10** may also include a sensor **500** operably engaged with the analyzer device **300**, wherein such a sensor **500** may be configured to determine when the advancement of the roll **350** has stopped and when the

sampling device **100** is prepared for a measurement with only one of the bands **60, 70** spanning the sampling area **250**. Upon sensing the necessary conditions, the sensor **500** may actuate the gas supplies **180, 230** to start the gas flows, may actuate the mass flow sensors **190, 240** to appropriately regulate the gas flows, and then actuate the analyzer device **300** to perform the measurement at the appropriate moment. However, one skilled in the art will appreciate that several sensors or other mechanisms may be implemented to perform such tasks.

Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. For example, embodiments of the apparatus **10** as described herein may be controlled by, incorporate, or otherwise include a computer device (not shown) such as a computer, controller, or the like capable of controlling any or all of the described components and/or functions of the apparatus **10**. In addition, where such a computer device is included, one skilled in that art will appreciate that associated methods and computer software program products will be within the spirit and scope of the present invention. Further, one skilled in the art will appreciate that the described apparatus may be other wise configured or include additional components so as to be capable of determining other properties of the cigarette paper wrapper **50**, such as, for example, a tensile strength or porosity thereof (that may be related to the diffusion coefficient D_p), other than those properties described in detail herein. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.